Theoretical Overlay Photographic Collector Alignment Technique (TOPCAT)

Performing Organizations: Sandia National Laboratories (SNL)

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FY 2008 Budgets: $580K (SNL) *FY 2009 Budget:* $550K (SNL)

Objectives

- Improve algorithms for calculating amount of mirror misalignment
- Align parabolic trough loops in commercial parabolic trough power plants
- Reconfigure TOPCAT rig for testing LS-3 geometry troughs

Accomplishments

- Acquired alignment data and aligned 6 trough modules at the Saguaro Solar Plant
- Acquired alignment data for one complete loop of every LS-2 solar plant in California
- Aligned two LS-2 trough loops, one at SEGS VI and one at SEGS II
- Initiated design of an improved field characterization system for LS-2 and LS-3 collectors
- Invented an improved algorithm for module-to-module alignment

Future Directions

- Align one or more LS-2 and LS-3 loops and accurately characterize and document improvements
- Design a pickup truck mounted TOPCAT system
- Continue work on licensing TOP Alignment technology. Interest from Abengoa Solar, Sun Ray FPL Energy, Klondyke, Inc., and Advent Technologies.

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1. Introduction

Parabolic trough solar power plant technology is the current lowest cost solar option for electricity production, yet unsubsidized electricity from parabolic trough power plants costs about twice that from conventional sources. The overall objective of the Theoretical Overlay Photographic Collector Alignment Technique (TOPCAT) project is to develop an optical evaluation approach that can rapidly and effectively evaluate the alignment of mirrors in parabolic trough power plants and prescribe corrective actions as needed. The approach could be used during plant construction; used to improve the performance of existing power plants; or be used for routine maintenance. It is also an enabling technology for higher concentration ratio and lower cost trough solar collector designs. An objective is to evaluate the optical alignment of existing trough power plants, and improve alignment and measure benefits. Licensing of the technology to trough developers and/or plant operators is also an objective.

2. Technical Approach

In the Theoretical Overlay Photographic Collector Alignment Technique (TOPCAT) an alignment fixture is placed at a convenient distance from the trough collector, fig. 1. This distance is close enough to be within the rows in a power plant, but far enough away so that a camera can see an entire module (20 mirrors in an LS-2 module). The fixture is essentially a pole with five cameras accurately positioned along it. The fixture is raised or lowered to center the fixture on the module. The trough is positioned horizontally (0^{o}) in elevation and the fixture is positioned vertically with levels. Images from the four cameras, which correspond to the four mirror rows, are then used to measure the alignment of the mirrors in each of the rows in the module. Each camera records the location of the receiver image in each mirror in a digital photographic image. The cameras are positioned to coincide with the mirror centers to minimize the influence of focal length variations on alignment. The receiver image location in the photograph is then compared to the theoretical projected image location by overlaying the two images. Vector algebra and projection theory are used to predict the theoretical projected image for perfectly aligned mirrors. The mirrors are then adjusted to bring the measured image to coincide with the theoretical image.

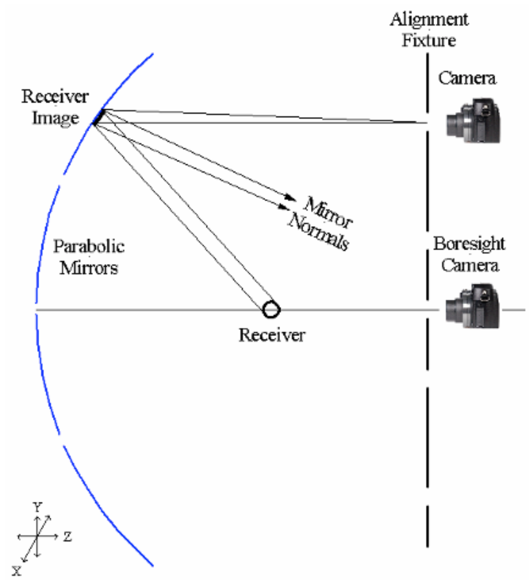

Fig.1. Schematic of the TOP alignment approach.

3. Results and Accomplishments

The development of the Theoretical Overlay Photographic Collector Alignment Technique (TOPCAT) has been a stepped approach. The concept was first validated on a LS-2 module at Sandia using a Nikon D-70 digital camera. Next, a first-generation field deployment prototype was developed and refined following field tests at the 1 MW_e Saguaro Solar Plant. The field deployment prototype system featured a trailer-mounted fixture, fig. 2, and utilized 2 mega pixel (MP) FireWire-A video cameras. During data acquisition with the prototype TOPCAT system a field crew would install and remove bore sight gauges on the modules as a driver/optical technician guided the fixture trailer until the cameras were centered on a module. After raising or lowering the fixture to bore sight the center camera on axis with the receiver and trough module and checking the verticality of the fixture, images were taken and stored in a database. The fixture was then driven to the next module and the process repeated. The images were processed later using National Instruments (NI) Vision image processing and analysis software for LabVIEW™, and work orders detailing alignment adjustments created. Alignment adjustments were subsequently made later, even while the plant was operating.

During the winter of 2008, the TOPCAT field deployment prototype was used to acquire data from one loop of every LS-2 trough plant in California. (A typical loop contains 96 modules.) The average time to acquire data was reduced to about 35 seconds per module, half the time required in previous benchmarking tests at Saguaro the previous year. The data was then used to align one loop at SEGS VI and SEGS II collectors. An approximate 10°F increase in loop temperature was observed at SEGS VI as compared to its neighboring loops, before and after alignment. No improvement was seen at SEGS II. The root cause for the lack of expected improvement was determined and significant improvements to the algorithms for establishing alignment between individual modules on a Solar Collector Array (SCA) were developed. (The especially poor receiver position repeatability within SCAs at SEG II contributed to the lack of improvement.) Additional process lessons-learned were also incorporated. Quality processes for implementing the alignment were developed and preliminary bench mark measurements of labor and material requirements were made. The resulting cost per MW_t benefit was determined to be a small fraction of the cost of installing new SCAs.


Fig 2. Photograph of the TOPCAT field deployment prototype system.

Based on the results of the TOPCAT field deployment system testing, a new algorithm for bore sighting that does not require the use of bore sight gages was invented and implemented in the TOPAAP LabVIEW™ analysis program. In addition, a design for a second-generation TOPCAT field characterization system was initiated. The new system features a pickup truck mounted fixture, and 5 MP Gigabit Ethernet (GigE) video cameras. In addition, the data acquisition, (TOPDAQ), and analysis, (TOPAAP), programs were significantly enhanced compared to the first versions. The new system is also capable of characterizing both LS-2 and LS-3 parabolic trough solar collector geometries. With these enhancements the data acquisition time is expected to be less than 30 seconds per module. Considering that there are close to 5,000 modules for each 30 MW LS-2 trough plant, reducing acquisition time is very important. Mounting the camera fixture in the bed of a pickup truck also reduces the setup time at the beginning of each row and improves overall mobility.

Analysis of the images has also improved. Edge detection has been enhanced largely through higher resolution and higher quality photographs. Much of the improvement is a result of improved contrast control during the image acquisition. This has greatly improved the accuracy of the overlays and reduced the amount of manual interaction in analyzing the images.

Data acquisition and analysis of pre alignment performance was initiated for a planned alignment campaign during the winter of 2009. This data along with identical measurements following alignment will allow for accurate quantification of performance benefits using a comparative calorimetric technique. In this approach the temperature increase through the loops, before and after alignment, is compared with neighboring loops. This calorimetric technique inherently accounts for variations in insolation levels, sun incident angle, and mirror and heat collection element (HCE) glass envelope cleanliness.

4. Planned FY 2009 Activities

The primary focus will be on the following.

- Shakedown testing of the pickup truck field characterization TOPCAT system.
- Characterize a large number of LS-2 and LS-3 collectors.
- Align at least one LS-2 and one LS-3 trough loop and quantify and document performance improvements.
- Refine benchmark measurements of labor hours and materials along with a detailed cost/benefit analysis of the TOPCAT system.

5. FY 2008 Special Recognitions, Awards, and Patents

None

6. Major FY 2008 Publications

Richard B. Diver and Timothy A. Moss, 2007, “Practical Field Alignment of Parabolic Trough Solar Concentrators,” ASME *Journal of Solar Energy Engineering*, Vol. 127, 153-159.

Richard B. Diver, Timothy A. Moss, 2008, “Development of a TOP Alignment System for Parabolic Trough Solar Collectors” Proceedings of 2008 14th Biennial CSP Solar PACES Symposium, Las Vegas, NV.

7. Acknowledgements

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